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Agricultural Memorandum No 802
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VERNALISATION OF SUGAR BEET SEED

1. Background. Sugar beet is normally a biennial plant, flowering the year after sowing. However, a variety of circumstances can cause plants to flower the first year or "bolt". These bolters cause loss of yield and difficulties with harvesting and subsequent processing. The subject is reviewed by Longden, Scott and Tyldesley (1975) who present evidence that the cause of bolting may be genetic, or may reside in the environment of the young beet plant or that of the seed on the mother plant. This note is concerned with the conditions encountered during the ripening of the seed, the effect known as "vernalisation on the straw".

2. Stations used. Sugar beet seed has been produced in widely separated areas of Europe, though of recent years the tendency has been to move the crop progressively farther south and east. This is claimed to have reduced the incidence of bolting, at least if genetic effects are discounted. Selected stations in the seed-growing areas are given in table 1.

Table 1. Selected stations with seed ripening periods.

Station	Lat °N	height above sea level (m)	ripening period
Visby, Sweden	58	11	mid June - end October
Cranwell, England	53	62	July - mid September
Bordeaux/Toulouse, France	44	106	mid May - end July
Ancona, Italy	44	104	mid June - end July
Kestamon, Turkey	41	790	mid June - 3rd week in July

The ripening periods are taken from Scott (1968), fig 2. Table 1 shows that as seed production moves to lower latitudes, it tends to be undertaken at greater heights above sea level, and the ripening period is progressively shortened.

3. The vernalisation response. The factors affecting bolting in beet are so complex and intertwined that it is difficult to get an unequivocal account of the effect of temperature during ripening (vernalisation on the straw) on induction of bolting in the resulting plants. However, it is thought that temperatures around 6°C are most effective. Temperatures below 2°C are thought to have no effect. Temperatures above 10°C also do not promote vernalisation, indeed they may have some devernalisation effect. In fig 1 response curves based on this information are sketched. The vertical axis represents the rate of progress towards vernalisation, in arbitary units.

4. Integrating the vernalisation response through the ripening season. When the response of an organism to temperature can be represented by a simple linear increase above a base temperature, then the time-integrated response is given by the accumulated temperature above T_o, and numerous well-established techniques exist for estimating the number of degree-days involved. In Agricultural Memorandum 702, this idea was extended to the case of a curve consisting of N connected linear segments, with break-points at $T_o T_1 \ldots\ldots T_{N-1}$ and gradients $a_1, a_2 \ldots\ldots a_N$. It was shown that in such a case, the time integrated response is given by

$$\int R\,dt = \sum_{o}^{N-1} (a_{n+1} - a_n) A_n \qquad (1)$$

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where A_n is the accumulated temperature above break-point temperature T_n.

Applying this result to the response curve of fig 1,

$T_0 = 2^oC$ $\quad a_0 = 0$
$T_1 = 6^oC$ $\quad a_1 = 1$
$T_2 = 10^oC$ $\quad a_2 = -1$
$\quad\quad\quad\quad a_3 = -k$

giving

$$V = \int Rdt = (1-0)A_0 + (-1-1)A_1 + (-k+1)A_2$$

$$V = A_0 - 2A_1 + (1-k)A_2 \qquad (2)$$

Two simple cases were investigated first, V_1 where segment DE in fig 1 applies, and V_2 where segment DF applies. The accumulated temperatures were assessed by Thom's method, using monthly mean temperatures and standard deviations of monthly mean temperatures for 1931-60. The results are given in table 2.

Table 2. Vernalisation response with two assumptions.

Station	V_1	V_2
Visby	47	- 584
Cranwell	0	- 452
Bordeaux/Toulouse	0	- 638
Ancona	0	- 589
Kestamon	0	- 353

There is a positive vernalisation response V_1 at Visby, on the island of Gotland in the Baltic, and elsewhere it is zero. This arises because only at Visby does the temperature in an average year fall below 10^oC during the ripening season, though it should be pointed out that temperatures lower than this would occur at Cranwell in a cool year. Seed growers would regard Visby as the station most prone to vernalisation, but would not regard it as realistic to lump all the other stations together as having zero vernalisation. In particularly, Cranwell would be regarded as much more prone than the Bordeaux/Toulouse area.

Looking now at the column headed V_2, where a devernalising effect at high temperatures is brought in, the larger negative values correspond to the most devernalisation (the least bolting). Though the French area is regarded as one of the best for producing bolting-resistant seed, to put Visby and Ancona on a par, and both much more resistant than Kestamon in Turkey, is quite unrealistic. It can be seen that the possible devernalisation effect has swamped the much better established vernalisation between temperatures of 2 and 10^oC. The next step therefore was to explore situations where the line DG in fig 1 had values of k in the range 0-1, corresponding to a less intense devernalising effect. This is referred to as V_3. V_1 is of course a special case of V_3 with k = 0, and V_2 another with k = 1, so the results of table 2 are repeated in the appropriate place in table 3. Also given is the rank of each station, low bolting being 1 and high bolting 5, for each value of the devernalisation coefficient k. All the stations except Visby maintain their relative positions in the table as k is decreased, since they have temperatures continuously above 10^oC during the ripening periods. The main effect of decreasing k is to push Visby to its rightful place at the bottom of the league table, and this is achieved with k = 0.15 or less. The column for k = 0.15 probably best reflects the seed agronomists' present thoughts on the relative merits of the areas, since when k is depressed to 0.1, Cranwell has a V of magnitude nearly 3 times that of Visby.

Also given at the right of table 3 is the mean temperature during the ripening season

Table 3. Vernalisation response with different values of the devernalising coefficient k.

Station	response V_3							rank of response, low bolting 1, high bolting 5.							mean T(°C)	rank on T
k =	1	0.75	0.5	0.25	0.15	0.1	0	1	0.75	0.5	0.25	0.15	0.1	0		
Visby	-584	-426	-269	-111	-48	-16	47	3	3	3	4	5	5	5	13.7	5
Cranwell	-452	-339	-226	-113	-68	-45	0	4	4	4	3	3	3	1=	15.9	4
Bordeaux/Toulouse	-638	-479	-319	-160	-96	-64	0	1	1	1	1	1	1	1=	18.4	3
Ancona	-589	-442	-295	-147	-88	-59	0	2	2	2	2	2	2	1=	22.8	1
Kestamon	-353	-265	-177	-88	-53	-35	0	5	5	5	5	4	4	1=	19.2	2

(a measure which takes no account of the temperature range or the time element) and the corresponding ranking. It has to be admitted that this gets the two most northerly stations into their correct positions, but it is doubtful whether the depression of France to third place is correct.

5. Conclusions. The sketchy knowledge that is available on vernalisation of beet seed on the straw in different parts of Northern Europe and around the Mediterranean, is consistent with a temperature response as shown in fig 1, provided that the vernalisation response below 10°C is much sharper than the devernalisation response above 10°C. With the benefit of hindsight, the line DG in fig 1 has been drawn at the gradient of - 0.15 which seems best to fit the limited information available. It is hoped that this conclusion will be of use in guiding the range of variables in future experiments, both in the field and in the laboratory.

6. Acknowledgement. Mr LDJ Harvey of the agrometeorology unit at Cambridge, kindly calculated some of the accumulated temperatures using a programmed desk machine.

References

Longden P C, Scott R K, and Tyldesley J B (1975) Bolting of sugar beet grown in England. Outlook on Agriculture, 8, 188-193.
Scott R K (1968) Sugar beet seed growing in Europe and North America. IIRB Journal 3, 54-84.

Any comments or suggestions on this paper should be referred to the author.

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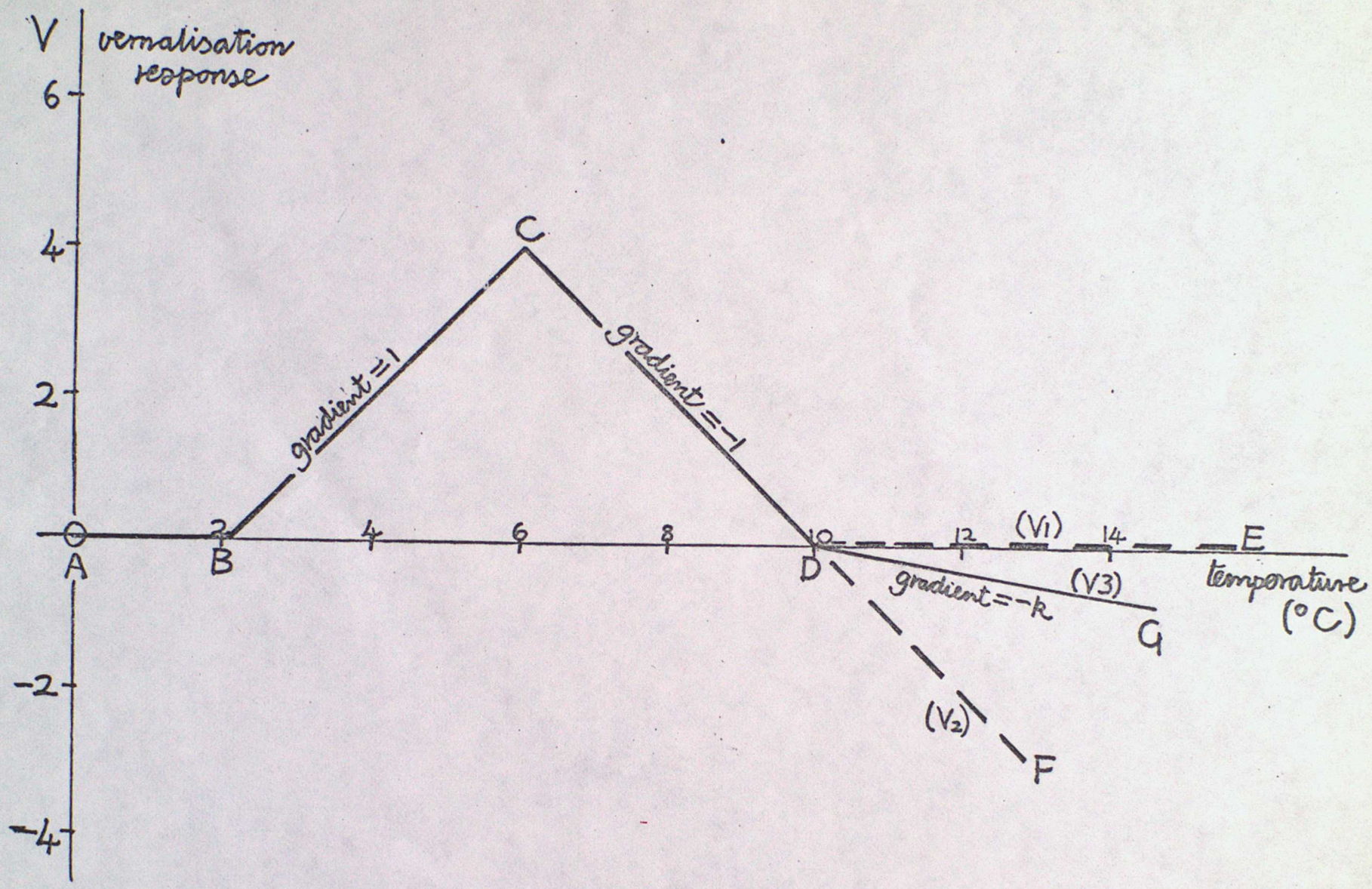

Fig 1. Different vernalisation responses for sugar beet seed